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Published in:
Restoration Ecology

Publication date:
1994

Assessing Restoration Perspectives of Disturbed Brook Valleys: The Gorecht Area, The Netherlands

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Abstract

Several landscape restoration alternatives were evaluated in the Gorecht area, a cultivated river plain in the northern part of the Netherlands. A landscape analysis was performed to investigate the hydrological functioning of this area. Groundwater composition in the area was assessed by using distribution patterns of indicative plant species. Results proved to be consistent with an interpolation of actual data of the groundwater composition. Groundwater flow was simulated with hydrological models to explain the observed patterns in water chemistry. It appeared that upwelling Ca-rich groundwater is now absent in the area, contrary to the past situation. Because a constant supply of Ca-rich water is an essential condition for mesotraphent fen vegetation, we concluded that under the present conditions the regeneration prospects for these vegetation types are poor. We suggest that the plan to regenerate groundwater-fed fens be abandoned for a plan to create surface-water-fed marshes.

Nomenclature

Common names of the phanerogams follow Clapham et al. (1962); scientific names are after Tutin et al. (1964–1980). Hydrological terms are after Unesco/World Meteorological Organization (1974) and Hooghart (1986).

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Introduction

Before the Middle Ages, the river valleys of the Northwest European Lowlands were covered with vast mesotrophic wetlands. From then onwards, these areas were increasingly exploited, at first for fuel supply (peat digging) and later for agricultural purposes (meadows). In the Netherlands, all large, undisturbed fen systems have completely disappeared; only some small remnants have been preserved as nature reserves. Despite careful management aimed at creating optimal conditions for the ecosystems involved, these reserves continue to decay. Therefore, many authors (Van Wirdum 1979; Kemmers 1986; Grootjans et al. 1988; Wassen 1990; Everts & de Vries 1991) conclude that the main causes of this deterioration are to be found outside the reserves. They stress the importance of water flow as a major factor in fen development and relate vegetation changes inside the reserves to interferences with the hydrology outside the reserves. An increase in biomass production after a lowering of the groundwater table is often observed (Gotkiewicz 1977; Grootjans et al. 1985), but the same effects can occur with constant water levels after changes in the chemical composition of the phreatic water. For instance, the substitution of Ca- and/or Fe-rich groundwater by mineral-poor water can release large amounts of phosphate in P-limited fen systems (Boyer & Wheeler 1989; Wassen 1990). So, when alternative scenarios for the regeneration of valley mires are to be judged, an evaluation of the hydrological consequences of each plan should play a key role in the comparison.

The present study was carried out to investigate the hydrological functioning of such a disturbed river valley. It started with a landscape analysis meant to distinguish between areas with different hydrological and hydrochemical conditions. We suspected that the observed pattern was caused by the influence of different water flows in different sites. We investigated this further by measuring the chemical composition of the groundwater in deeper strata and by simulating water flow paths with numerical models. The obtained insight into the hydrology was used to judge the effectiveness of several alternative landscape restoration strategies.

Materials and Methods

Description of the Area. The study was carried out in the Gorecht area (Figure 1), a valley of approximately 1000 ha, in the lower course of the river Hunze, situated in the northern part of the Netherlands (53°08′N and 6°40′E). The area lies at the foot of the Hondsrug, an ice-pushed moraine ridge (Figure 2) that rises to 8 meters above mean sea level. It consists of Pleistocene

Figure 1. The Gorecht area viewed southward, with *Phragmites australis* (reed) and *Salix viminalis* (willow) in the foreground. Parallel ditch lines are faintly evident, and a small forest occurs to the left where a former peat pond is being transformed into alder carr.

sand layers that form an aquifer more than 200 meters thick, covered with a 1–2 meter thick Saalien clay layer. Although this top layer has a considerable resistance to water movement, the Hondsrug functions as an infiltration area that replenishes the groundwater body.

The moraine ridge has been inhabited since at least the Stone Age, while the cultivation of the valley started in the Middle Ages, when the area probably was used extensively for cattle herding. In the eighteenth century peat cutting became important, especially in a zone close to the moraine, and this continued until the 1930s (Clason 1928/1929). The remaining peatland was drained and split up into several polders, each with its own controlled surface-water level. The river Hunze was embanked and regulated some centuries before.

Around 1900, practically the whole area consisted of low productive grasslands, with characteristic plants such as *Caltha palustris* (kingcup), *Molinia caerulea* (purple moor-grass), *Cirsium dissectum* (meadow thistle), and *Succisa pratensis* (devil's-bit scabious) (Clason 1928/1929; Dutch State Herbarium, unpublished data). At present these meadows are used intensively for dairy farming. The application of fertilizer is high (200–300 kg N/ha), and, consequently, species diversity is very low. Only the former peat ponds—now terrestrialized—deviate from this picture. Until the 1960s they were mainly covered with mesotraphent sedge communities composed of species such as *Carex diandra* (lesser tussock sedge), *Carex lasiocarpa* (slender sedge), *Carex rostrata* (bottle sedge), *Menyanthes trifoliata* (buckbean), *Potentilla palustris* (marsh cinquefoil), and *Utricularia intermedia* (intermediate bladderwort). A few fens have been protected as nature reserves and are mown each summer in an attempt to prevent the succession to reedland or woods. Repeated vegetation recordings since 1972 showed even there a strong decline in the occurrence of the characteristic calciphilous vegetation types in favor of eutraphent ones, suggesting a decrease in the supply of base-rich water.

The soil consists of fen peat of varying thickness (0.5–3 meters). Underneath the peat, several meters of eolic sandy deposits are found, forming the first aquifer. Geological investigations proved the existence of a 5–10–meter thick layer of Eemien clay at a depth of about 10 meters below the surface. This clay has a high resistance to water movement. In the northern half of the area, a 10–35–meter thick Elsterien clay layer is found just below the Eemien clay, forming an absolutely impermeable barrier to groundwater flow. Under these clay layers, relatively coarse meltwater sands are present down to about 250 meters, where an impermeable clay layer, underlying the main aquifer, is reached.

In the center of this polder a large groundwater extraction facility is situated (1988: 10 millions m^3) that takes its water from the second aquifer. The surface-water management aims at creating optimal circumstances for agriculture, which results in a substantial lowering of the water table during the wet season. The resulting water shortage during the summer is compensated for by the inlet of surface water.

Recently, the area has been designated to become part of the so-called "ecological infrastructure" of the Netherlands (Ministerie van Landbouw en Visserij 1989). This means that nature conservation will be the major function in most of the area, while agriculture will be restricted to a smaller part. At present, conservation organizations are buying land and making plans for landscape restoration.

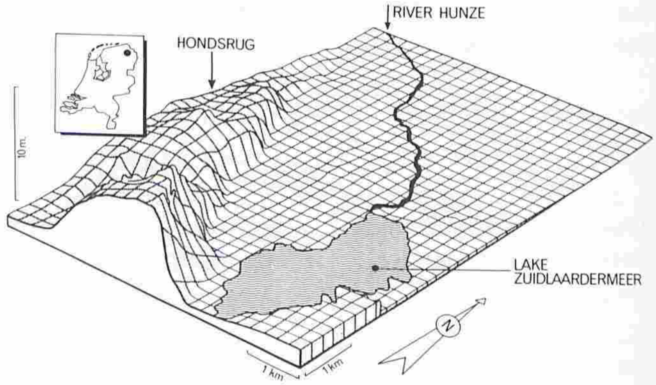

Figure 2. Altitude map of the Gorecht area. Areas over one meter above mean sea level are shaded. The study area is situated between the moraine ridge (Hondsrug) and the river Hunze.

Identifying Land Units. The landscape analysis started with the delineation of so-called "land units" (Zonneveld 1989) or "ecotopes" (Klijn & Udo de Haes 1990)—parts of the landscape that can be considered to be ecologically homogeneous on the scale studied. The discrimination was based on the hydrologically relevant parameters of soil type, presence or absence of a regime of controlled surface-water levels, presence or absence of Elsterien clay (making upward seepage of groundwater from the aquifer impossible), presence of absence of iron precipitates in the surface water (considered to reveal actual groundwater discharge) (Everts & de Vries 1991), and differences between mean summer and mean winter water levels (Commissie Onderzoek Landbouwaterhuishouding Nederland 1954). The area was overlain with a grid of 250 by 250 meters, and land units were created by aggregating cells that had the same value for all parameters.

These parameters are, however, only indicative of differences in water levels. To assess the chemical composition of the groundwater, nine common plant species were used as indicators. All belonged to natural and seminatural vegetation types within the lower course of brook systems in the Netherlands (Barkman & Westhoff 1969; Grootjans 1980). The indication value of these species was derived from detailed hydroecological investigations in adjoining stream valleys (Everts & de Vries 1991) (Table 1).

Groundwater Chemistry. The chemical composition of the groundwater was measured in 50 samples from the phreatic water (between 1.50 and 5.00 meters below the surface) and 70 samples from deeper strata (between 5 and 220 meters). All samples were taken from capped piezometers situated along five transects, three perpendicular to the river and two parallel to it. The phreatic piezometers were emptied one day before sampling to allow refilling with fresh groundwater. It was impossible to empty the deeper wells, and therefore water was pumped up until its temperature and EC_{25} (electrical conductivity at 25°C) remained constant. EC_{25}, temperature, and pH were measured directly in the field with portable equipment. We took a 150-ml sample from each well, put them in polyethylene bottles, and stored them for seven days at 4°C in a darkroom. Prior to analyzing them, EC_{25} and pH were determined again in the samples to check whether shifts in chemical equilibria had occurred. Only samples that had remained constant were processed. A subsample of 50 ml was brought to pH 2 by the addition of 2.5 ml 4% HCl and used to measure cation contents (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe_t, Al_t, and Si_t) by an inductively coupled plasma technique (Boumans 1987; Bos & Fredeen 1989). Anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, and $H_2PO_4^{2-}$) were measured with an auto-analyzer (Skalar). To check the reliability of the analyses, both the charge balance and EC_{25} were computed. Unreliable analyses—a deviation in the charge balance of more than 10% from electro neutrality or a difference in computed versus measured EC_{25} of more than 15%—were discarded.

Before the data were further processed, the main variation in water chemistry was analyzed using a principal components analysis with Varimax rotation (Norusis 1990). The data of the phreatic water were entered in the Geographical Information System ILWIS (Valenzuela 1988), and values between sampling points were estimated with a moving average interpolation (Burrough 1986). In several deeper layers, too few samples were present per transect to yield a reliable interpolation, so these data were only classified. We used a classification by Stuyfzand (1989) based on chloride contents and total hardness. The results were depicted in three east-west transects, to-

Table 1. Preference (■■) of plant species for groundwater types.

	Water Type Chloride (mg/l) Total Hardness (mmol/l)	II <150 0.5–1	III <150 1–2	IV <150 2–4	V >150 >0.5
	Number of Samples				
Hottonia palustris	17	■			
*Menyanthes trifoliata**		■			
Potentilla palustris	14	■			
*Carex lasiocarpa**		■			
Carex rostrata	50	■	■		
Ranunculus lingua	19		■	■	
Carex aquatilis	11	■	■	■	
Equisetum fluviatile	101	■	■	■	
Caltha palustris	48	■	■		
Hippuris vulgaris	6				■

Based on data from Everts and De Vries, 1991. Species marked with an asterisk were mentioned in the text in Everts & De Vries (1991), but actual data were not presented.

gether with geological information (aquifers and aquitards).

Quantitative Hydrological Modelling. The nonstationary finite element model SIMGRO (Querner 1988) was chosen to evaluate the hydrological conditions under different land-use scenarios. This model can simulate the groundwater fluctuation pattern in several layers, given the geological conditions, precipitation per day, and the ground- and surface-water management regimes. The modeled area was chosen to be 2.5 times larger than the study area, minimizing erroneous results due to edge effects. It was schematized into four layers (top layer, first aquifer, semipermeable layer, second aquifer) in 506 nodes, evenly distributed over the area. The water balance of each layer in each node was computed per day under the assumption that the water can flow only in a vertical direction between the layers and only in a direction horizontal to the adjacent nodes. The area between the nodes was assigned to the nearest node.

The input to the model consisted of hydraulic conductivity values (measurements in 1962 and 1971, supplemented with literature data), meteorological data (daily measurements at a nearby weather station), surface water levels (semiweekly measurements at 28 sites), and amounts of groundwater extracted (weekly data from the drinking-water companies). Piezometric heads were measured in the field every 14 days in the years 1987 and 1988 in 137 piezometers with filters in several aquifers. The SIMGRO model was calibrated with the 1987 data set. Validation of the model was performed with the 1988 data by comparing measured and predicted values. The absolute deviations between measured and calculated water tables were 0.07 meters on average although the deviations were larger (up to 0.35 meters) in areas on the flanks of the Hondsrug. Here the occurrence of semipermeable Saalien clay lenses led to perched water tables that could not be modeled reliably.

The groundwater flow under average spring conditions was visualized with the computer program FLOWNET (Van Elburg & Engelen 1986). This steady-state model calculates the stream lines in a vertical plane, given piezometric head along all boundaries of the modeled section. The model was subdivided into cells of 5 (vertical) by 50 meters (horizontal). Values for porosity and permeability per cell were taken from the SIMGRO model. The values for piezometric head along the boundaries consisted of the average of three measurements between March 27, 1987, and April 28, 1987.

Results

Distinguished Land Units. The major environmental gradient in the study area lies along a west-east axis from the moraine ridge to the river. The river plain can be divided into three main zones (Figure 3; Table 2).

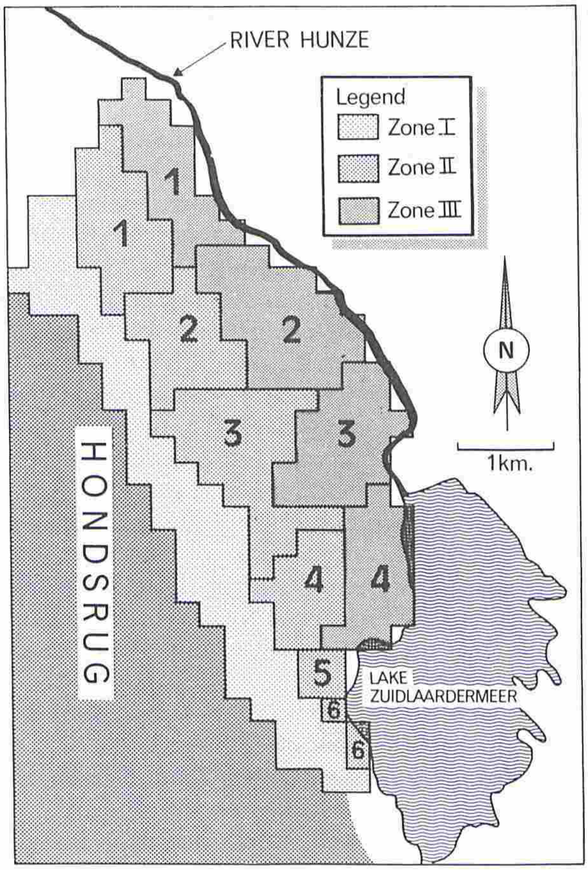

Figure 3. Division of the study area into environmental gradients (Zones I–III) and land units per zone (1–6). Properties of each land unit are presented in Table 2.

Zone I, at the foot of the moraine ridge Hondsrug, is characterized by relatively large water-table fluctuations. The soil consists of a shallow peat layer (less than 40 cm) on top of sandy deposits. It is characterized by a high presence of species that are indicative of mineral-poor water. *Hottonia palustris* (water violet) is practically restricted to this zone, while *Menyanthes trifoliata* and *Carex lasiocarpa* are also not uncommon here.

In the intermediate Zone II, the soil consists of thick peat (generally 2 to 4 meters) without a clay layer. This zone was subdivided into six units, which differ mostly in groundwater levels. The central area shows somewhat larger water-table fluctuations than do the peripheral parts. Plant species' indications show a shift towards harder groundwater, even though the mineral-poor class still predominates (Table 2). The area is mainly characterized by species belonging to small sedge communities: *Menyanthes trifoliata*, *Potentilla palustris*, *Carex lasiocarpa*, and *Ranunculus lingua* (great spearwort) are most common in this zone.

Zone III lies along the river Hunze, where the peat is

Table 2. Characteristics of the distinguished land units.

Zone	Land unit	Soil Type (1)	Controlled Surface-Water Levels (2)	Elsterien Clay (3)	Iron Precipitation (4)	Annual Groundwater Amplitude (cm)	Percentage of Plant Species Indicative of Water Type			
							II	III	IV	V
I		fen peat (<50 cm)	−	−	−	55	58	27	12	3
II	1	fen peat (>50 cm)	+	+	−	20	54	29	15	3
	2	fen peat (>50 cm)	+	−	−	0	48	33	19	0
	3	fen peat (>50 cm)	+	−	−	45	54	29	16	1
	4	fen peat (>50 cm)	+	−	−	20	52	32	16	0
	5	fen peat (>50 cm)	−	−	−	<20	47	30	15	8
	6	fen peat (>50 cm)	−	−	+	<20	57	26	17	0
	Average II						52	29	16	3
III	1	peat covered with clay	+	+	+	25	42	36	22	0
	2	peat covered with clay	+	−	−	45	38	42	20	0
	3	peat covered with clay	+	−	−	45	42	39	19	0
	4	peat covered with clay	+	−	−	45	43	32	15	10
	Average III						42	36	18	4

Data are taken from soil maps (1), hydrological maps (2), geological maps, (3) or unpublished reports (4). Features that were either present or absent are denoted by "+" or "−". The annual groundwater amplitude was computed by subtracting values of mean summer water level from mean winter level. Basic data were taken from Commissie Onderzoek Landbouwwaterhuishouding Nederland (1954). The number of indications per watertype was obtained by counting the occurrences of plant indications per land unit. Each entry was assigned to the water type the species was considered to be indicative of (see Table 1).

covered with a 15–30–cm thick clay layer. It was subdivided into four units, based on the division into different polders and the presence or absence of Elsterien clay in the subsoil. The southernmost unit III-4 is characterized by a strong precipitation of iron-hydroxide in many ditches. In comparison to the other two zones, plant indication values show a further shift towards harder water (Table 2). The characteristic plant species belong to productive plant communities: *Equisetum fluviatile* (water horsetail), *Caltha palustris*, *Hippuris vulgaris* (mare's tail). *Carex rostrata* and *Carex aquatilis* (water sedge) showed less distinct preferences; they are common in Zone II and III but seem to avoid Zone I.

Chemistry of the Phreatic Water. There was substantial variation in the chemical composition of the phreatic water. A principal components analysis of all samples showed that 75% of the variation was explained by the first four components. Salt content is the major differentiating factor, followed by a Ca-HCO_3 content, Fe-SO_4 content, and N content.

The salt content (Cl concentration) decreased from north to south. Relatively high values were encountered in land unit III-1 (Figure 4), while the groundwater contained low amounts in the rest of the study area, both in the river plain and on the moraine ridge.

The Ca content of the groundwater increased along a west-east gradient from the top of the moraine ridge to the polder areas (Figure 5). No further differentiation occurred within these zones, with the exception of zone III. The highest Ca concentrations in the groundwater were encountered in the northeastern land unit III-1.

Sulphate showed approximately the same pattern as chloride, although the gradient was steeper. High concentrations were measured in the northeastern corner, while the content was low in the rest of the area.

Nitrogen did not show a clear picture. Some very high values were found close to farms, but this was not

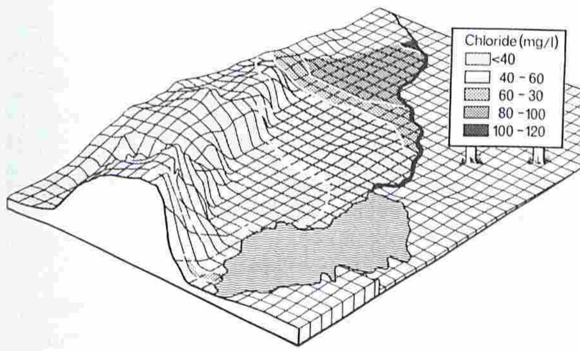

Figure 4. Chloride contents of the shallow groundwater (less than 5 meters below soil surface).

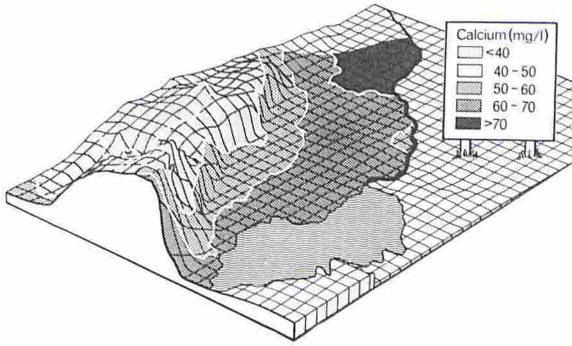

Figure 5. Calcium contents of the shallow groundwater (less than 5 meters below soil surface).

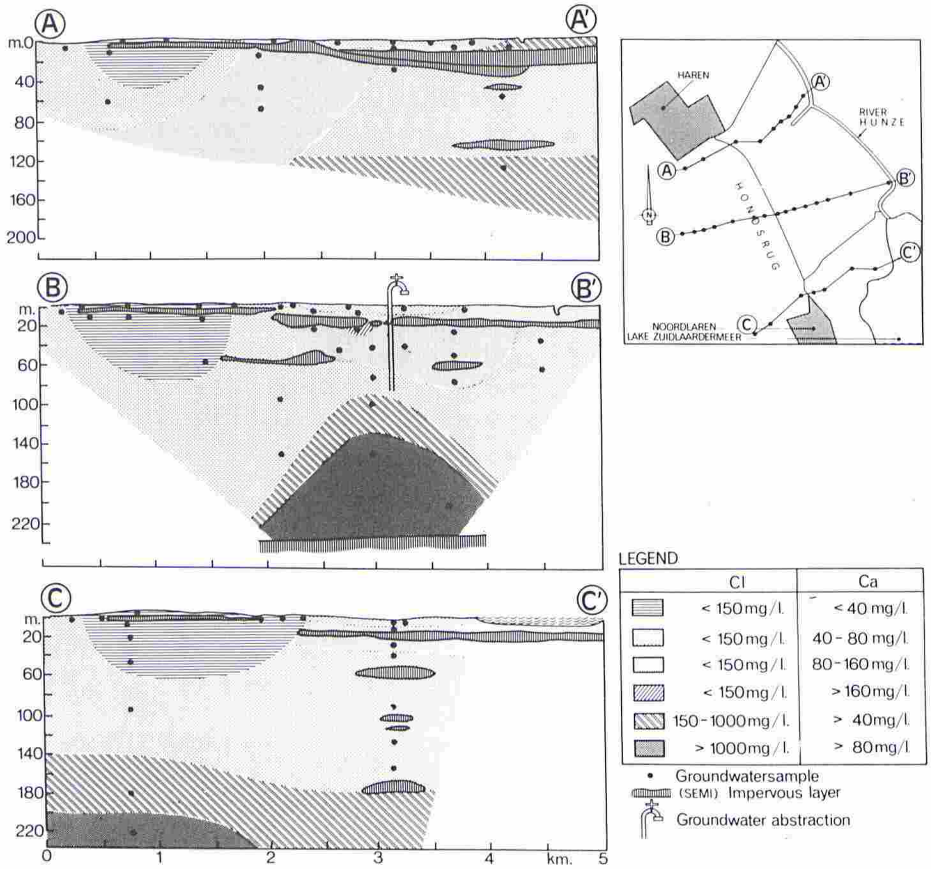

Figure 6. Distribution of water types in deeper strata along three cross-transects from moraine ridge to river. Depths are in meters above mean sea level.

always the case. In most of the area only insignificant concentrations were measured.

Geohydrology. Soft, Ca-poor groundwater is present under the moraine ridge to a depth of at least 40–60 meters (Figure 6). This water is still very much related to rain water chemically, and practically no minerals have dissolved.

In the polder area the groundwater extraction has considerably raised the boundary between salt and fresh water. In the research area the mean depth of this boundary lies around 150 meters below the surface, whereas it is found at a depth of only 100 meters in the vicinity of the pumping wells. The ratio of Na + K + Mg to Cl is larger than one around these wells, which suggests a saltwater intrusion (Stuyfzand 1989).

In a nearby well, some 100 meters south of the transect, groundwater samples were analyzed yearly in the period 1948–1963 and again in 1983 (Figure 7). These data show that both above (piezometer P51-11) and below the Eemien clay (P51-20), Ca and HCO_3 contents were increasing to very high levels in the first half of the fifties. In the shallow filter this increase halted around 1955 and decreased slightly afterwards, while in the deeper filter the increase continued at least until 1960. In both filters the contents significantly diminished in 1983, whereas Na and Cl contents rose.

Simulating Groundwater Flow. Computations with the hydrological model SIMGRO show that, at present, differences in piezometric head between phreatic and deeper groundwater are such that the groundwater movement in practically the whole polder is downward. Upward groundwater movement is predicted only in the northern part and in a small corner along

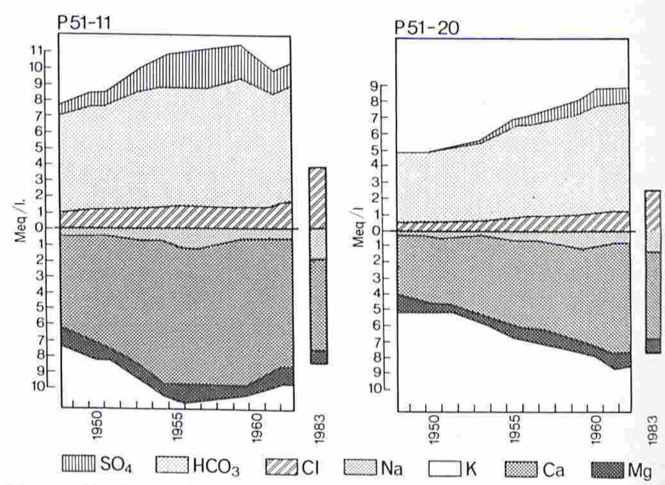

Figure 7. Groundwater composition above (P51–11) and below (P51–20) the Eemien clay layer in the period 1948–1963 and in 1983 (after Bohlmeijer 1985).

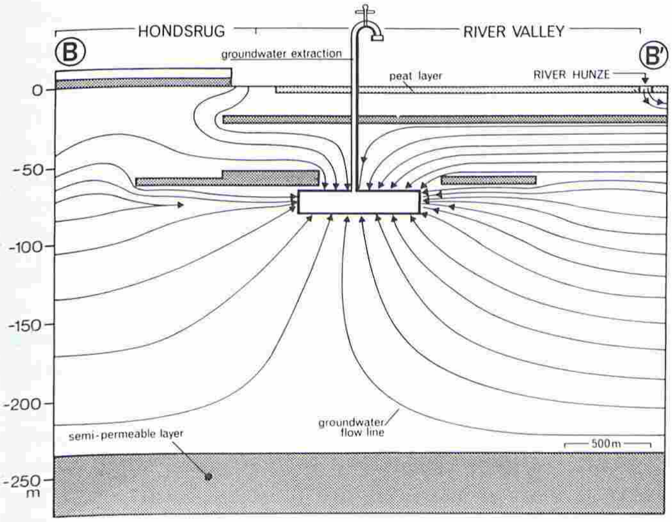

Figure 8. Simulation of groundwater flow along transect B-B′ (see Figure 6) under the present conditions.

the river Hunze. A visualization of these results with the program FLOWNET along a west-east transect shows that practically all water flow is directed towards the groundwater abstraction (Figure 8).

A simulation of a less disturbed situation without groundwater extraction and with raised surface-water levels shows a completely different picture. Piezometric heads in the several strata have changed in such a way that SIMGRO predicts upward groundwater movement in practically the whole polder area. The FLOWNET simulations show upward water flow to the polders as well (Figure 9). The contact zone between moraine ridge and polders, especially, receives a large quantity of upwelling groundwater.

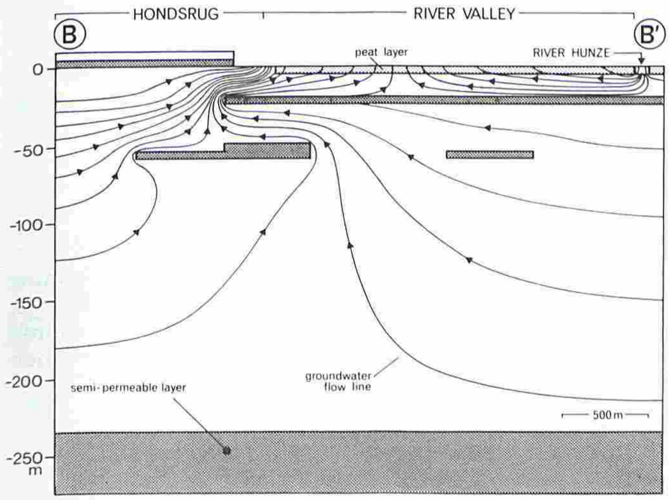

Figure 9. Simulation of groundwater flow along transect B-B′ (see Figure 6) without a groundwater abstraction and with raised surface water levels.

Discussion

Plant Species as Indicators of Groundwater Composition. In the present study, distribution patterns of plant species along ditch sides were used to assess the composition of the phreatic water. Several authors (Jeglum 1971; Grootjans et al. 1988; Wassen 1990; Everts & de Vries 1991; Van Diggelen et al. 1991*b*; Van Wirdum 1991) have shown that under natural and seminatural conditions a clear relationship exists between vegetation zonation and groundwater chemistry. In the modern landscape, however, this relation has become unclear as a result of agricultural practices such as fertilizer application and lowering of the groundwater table (Everts & de Vries 1991). Relics of more natural vegetation types can survive only along ditch sides (Melman 1991). In the present study, differences in hardness of the groundwater were indeed reflected in the distribution of plant species along ditch sides. Differences in chloride content were not revealed by plant indications, mainly because only one—relatively rare—species was indicative of salt. The well-known plant indication system from Ellenberg (1986), however, discriminates only between species that prefer salt and species that do not. Such a system may be satisfactory for distinguishing between extremes (Nieuwenhuis et al. 1991), but definitely not in the present situation.

An obvious disadvantage of the applied method is that plants, especially perennial species, respond slowly to environmental changes. Population studies of *Schoenus nigricans* (bog-rush), for instance, show that rejuvenation of this species diminished as a reaction to acidification (Ernst & Van der Ham 1988), but individuals already present survived for several decades in seemingly unfavorable conditions. Everts et al. (1988) quote an example of a *Cladium mariscus* (sedge) stand that had endured for tens of years in a drained area. Beeftink (1987) gives examples of several salt marsh species that have lasted for more than ten years after the removal of tidal influence in some estuaries in the southwest Netherlands.

Patterns in Water Chemistry in Relation to Groundwater Flow. Two clear gradients can be distinguished in the groundwater composition in the study area. The first gradient is characterized by an increase in the salt content from south to north. This brackish water is not present in somewhat deeper layers, suggesting a surface-water origin. A probable source is the inlet of water in dry periods before 1986 when the River Hunze contained slightly brackish water during the summer.

The second gradient is characterized by the Ca content of the groundwater, which increases from ridge to river. Such a gradient is observed more often in Dutch brook valleys and has been shown to be the result of admixture of different water flows (Grootjans 1980, 1985; Everts & de Vries 1991). Along the valley flank, a mineral-poor, relatively acid subsurface flow is dominant, which is replaced in the middle section by upwelling mineral-rich water from the aquifer. Regular flooding is the dominant process along the brook. This zonation in abiotic conditions causes a typical vegetation zonation to develop, both in natural peat-forming communities (Palczynski 1980, 1984; Succow 1988) and in seminatural replacement communities (Grootjans 1980; Weber 1982; Slobodda 1983). Analyses of peat remnants showed that in the past this same vegetation zonation had been present in the study area as well (Van Diggelen et al. 1991*a*).

At present, the observed Ca zonation is unlikely to be the result of admixture of different water flows. Flooding is no longer possible, and hydrological modeling shows that the whole area has turned into an infiltration area. Thus, explanations must be sought in differences in soil properties. Peat and clay soils especially can store a large number of cations on the cation exchange complex (CEC), and they release them gradually when the supply of these ions by ground and/or surface water has already halted. In a comparable situation with a secondary infiltration in a former discharge area, Schot & Wassen (1993) found very high Ca concentrations in the groundwater under such rheophilous peat deposits. They ascribed this phenomenon to a secondary dissolution of calcite under constant CO_2 pressure (open system dissolution) in which the used CO_2 is immediately replenished. The high levels of Ca and HCO_3 in two piezometers close to the groundwater extraction (Figure 7) could well be caused by secondary dissolution of these salts. The recent increase in Na and Cl suggests that the front of calcium dissolution has moved downward while the groundwater was replaced by infiltrating surface water. The presence of many shallow rain water layers throughout the area is in accordance with the view that the cation buffer in the top layers has been nearly depleted.

Regeneration Perspectives. At present, nature conservation organizations are studying possibilities of landscape restoration in the area. In fact, three alternative scenarios exist. The first is to restore the seminatural landscape with species-rich grassland that existed here around 1900 (Clason 1928/1929). A second is to recreate the natural landscape with peat forming fen communities, present until the Middle Ages (Van Diggelen et al. 1991*a*). The third is to let surface water flood the lower parts of the area, thus causing eutrophic marshes to develop.

If the first alternative is chosen—to restore low-productive, species-rich meadows from abandoned grasslands—a major problem consists in the large amount of nutrients stored in the soil (Bakker 1987, 1989; Oomes 1991). Nature managers generally try to remove these nutrients by means of techniques such as grazing or hay-making without fertilizer application, but this is often a very slow process (Wells 1980; Bakker 1989; Bakker & de Vries 1989). This alternative would entail expensive management practices for many years.

If the objective is the second alternative—to restore mesotraphent fen communities—the presence of mineral-rich, nutrient-poor water should be guaranteed. A strategy for such a restoration could consist of digging new turf ponds to start the terrestrialization process again. The mesotraphent fen species might then become reestablished. Such vegetation development would take a long time, at least some decades (Segal 1966; Van Wirdum 1991). Moreover, the prospects are not at all good. If the groundwater abstraction remains at its present level, the whole polder would remain an infiltration area and no groundwater would discharge into such ponds. They would collect rainwater, and acidophilous vegetation would develop instead of the desired fen vegetation.

A more definitive and original solution would be the reactivation of the seepage belt. This would necessitate a total termination of the groundwater abstraction and a large reduction in agricultural drainage. Although this is technically quite possible, the social costs of such an operation would be enormous, and political support probably would be small. Therefore, it might be better in this particular situation not to try to restore mesotrophic mires (fens), but instead to concentrate on eutrophic ones (surface water fed marshes). These can be created relatively easily by the input of nutrient-rich river water in the lower parts. In addition, such a nature reserve could act as a helophyte filter (Brix & Schierup 1989; Meuleman et al. 1990) for the purification of surface water, which can be used for part of the drinking water supply.

Acknowledgments

We thank N. Eck, W. A. van Hal, and P. Anten for performing the water analyses, and E. Leeuwinga for preparing the figures. J. van Andel, F. Sival, M. Wassen, A. Wierda, and two anonymous reviewers commented on earlier drafts of this paper; their help is gratefully acknowledged.

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